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Effects of high-intensity interval exercise on attentional network function in youth athletes

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Abstract

Introduction and Objective. The aim of the study is to explore the impact of high-intensity interval exercise (HIIE) on the attentional network function in youth athletes.
Materials and Method. A total of 44 youth athletes (mean age: 15.2 ± 1.1 years) were randomly assigned to either an experimental group (n = 22) or a control group (n = 22). The experimental group engaged in a 30-minute HIIE session, while the control group watched a 30-minute documentary. Attentional functions -including alerting, orienting, and executive control – were assessed using the Attention Network Test (ANT) immediately before and after the interventions.
Results. Post-intervention, the experimental group exhibited a significant improvement in executive control, with reaction times decreasing from 102 ± 15 ms to 89 ± 12 ms ($p < 0.01$). In contrast, the control group's reaction times remained relatively unchanged (pre-test: 101 ± 14 ms; post-test: 100 ± 13 ms; $p = 0.45$). No significant differences were observed between groups in the alerting effect (experimental: pre-test 35 ± 8 ms, post-test 34 ± 7 ms; control: pre-test 36 ± 9 ms, post-test 35 ± 8 ms), or the orienting effect (experimental: pre-test 42 ± 10 ms, post-test 41 ± 9 ms; control: pre-test 43 ± 11 ms, post-test 42 ± 10 ms).
Conclusions. HIIE significantly improves executive control network function in youth athletes, with limited effects on alerting and orienting networks. These findings suggest that HIIE can enhance cognitive functions, particularly executive control, which can inform the development of optimized training programmes for youth athletes.

Key words
High-intensity interval exercise, attentional networks, executive control, youth athletes

INTRODUCTION

Attention is a core cognitive function that governs memory, language, and decision-making processes. Given the relevance of attention in sports, particularly in strategic open-skill sports, its significance has undoubtedly been recognized [1]; for instance, in fast-paced team ball games, athletes are required to manage various attentional processes, ranging from moderate to high-intensity demands. They must simultaneously perceive the positions and movements of teammates, opponents, and the ball, while consciously deciding on the optimal course of action [2]. Recent research has highlighted attention as a key cognitive domain benefiting from physical activity [3]. Cognitive functions in various groups, such as adolescents, adults and athletes, have been shown to benefit from physical exercise [4]. In recent years, the impact of different types of exercise and exercise intensity on cognitive function has become a hot topic in research. Existing studies have demonstrated that a single bout of exercise (also referred to as acute exercise) has a transient enhancing effect on cognitive functions, including working memory, task switching, visuo-spatial ability, attention, and executive function, which has been well-supported by the majority of studies on this topic [5].

However, different acute exercise modalities or intensities appear to have varying effects on cognitive performance. For example, in a meta-analysis, Chang et al. reviewed the effects of acute exercise on cognitive function, revealing that exercise intensity and the timing of cognitive performance testing are key factors influencing the magnitude of the effect [6]. The authors noted that when cognitive performance tests are conducted immediately after exercise, lower intensity exercise is more beneficial, whereas if the test is delayed post-exercise, higher intensity exercise produces more significant effects. These results largely support the notion that acute exercise serves as a foundation for cognitive inhibition and attentional abilities, with even short-term exercise interventions being able to enhance executive function in overweight adults.

High-intensity interval exercise (HIIE) is a well-known time-efficient exercise method for improving cardiorespiratory and metabolic functions and can be safely applied to various populations [7, 8]. A substantial body of research indicates that acute HIIE can positively impact executive (cognitive) functions. For example, compared to control conditions, adults demonstrated faster overall reaction times and higher accuracy in the Flanker task 9 minutes after HIIE [9]. As measured by the Stroop test, HIIE had a greater impact on brain regions related to executive functions compared to moderate continuous exercise (MCE) [10, 11]. However, in another recent study, both HIIE and moderate-intensity intermittent exercise (MIIE) were found to enhance cognitive abilities [12]. Differences in exercise protocols—particularly in intensity and/or modality—and the specific timing of tests may account for these inconsistent findings [13]. A review of the existing literature indicates

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that exploring the relationship between HIIE and cognitive function has become a key focus of current research. There is a consensus on the positive effects of HIIE on cognition, and recent studies have primarily concentrated on the relationship between HIIE and executive control.

Despite growing research on the cognitive benefits of HIIE, its acute effects on attentional network function, particularly in youth athletes, remain under-explored. The presented study addresses this gap by assessing the differential impacts of HIIE on the alerting, orienting, and executive control networks. Additionally, in studies examining the effects of HIIE on attention, the experimental paradigms used by researchers sometimes fail to comprehensively reflect an individual's attentional function. In attention assessment tasks, researchers typically use the Stroop test, the A-B linking test, or the d2 test of attention to evaluate an individual's selective attention and sustained attention abilities. Most research on attention tends to focus on attentional characteristics. However, attention is a complex structure, and recent neuroimaging studies suggest that attention can be divided into three independent subfunctions: alerting, orienting, and executive control. Alerting refers to the state of being highly sensitive to external stimuli and ensuring sensitivity to incoming stimuli and response preparation, allowing for rapid perception and processing of stimuli [14]. Orienting is the ability to quickly select relevant information from numerous sensory stimuli [15]. The executive control network, also known as the conflict network, is involved in the self-regulation and resolution of conflicts between thoughts, emotions, and overt responses, detecting and resolving conflicts in responses [10]. However, current research seldom examines attention from the perspective of the three subnetwork functions of alerting, orienting, and executive control, and there is limited attention paid to the relationship between HIIE and attentional networks. As previously discussed, it is evident that the experimental paradigms and research approaches used in studies on the effects of HIIE on attention sometimes fail to comprehensively reflect an individual's attentional function.

In summary, there is currently a lack of HIIE studies that jointly assess the three attention networks, and research on the exercise-attention relationship has almost exclusively focused on the conflict control network. Youth athletes are at a critical stage of both physical and psychological development, and their training methods not only affect their physical fitness levels, but may also have profound implications for their cognitive functions. Attention network function, as an important component of cognitive function, is closely related to an athlete's performance. Therefore, exploring the impact of HIIE on the attention network function of youth athletes is of significant academic and practical importance.

MATERIALS AND METHOD

Participants. The automatic direct method available in G*Power, with a medium effect size of 0.25, significance level α = 0.05, power = 0.95 was used. The sample size obtained using G*power3.1.9.7 was calculated to be at least 28 cases. Forty-four highly fit youth athletes (19 females; mean age = 15.86; mean age = 1.36; 25 males; mean age = 15.77; mean age = 1.32), were randomly recruited through advertisements posted in a sports university and its affiliated sports schools in China. The main types of sports were round-based ball games (including badminton, table tennis and tennis). Prior to the experiment, all participants completed the International Physical Activity Questionnaire (IPAQ), and had to meet the following criteria: (1) at least three years of professional training experience; (2) qualification at national level 2 or as a higher athlete; (3) at least three training sessions per week over the past two years; (4) each training session lasted more than two hours; (5) right-handed, with normal or corrected vision, and no colour blindness or colour vision deficiencies; (6) no known neurological, cardiovascular, or pulmonary diseases, and no mental or neurological disorders; (7) participants were required to fast (overnight fasting), refrain from consuming caffeine and alcohol for 12 hours, and avoid taking any medications that could affect cognitive function; (8) participants were asked to avoid intense physical activity 24 hours prior to the experiment and had not participated in the ANT attention network test; (9) participants had no injuries or illnesses within the past six months.

Participants were informed of experimental procedures and potential risks and provided written consent to participate in the study. Written informed consent was given in accordance with the procedures and protocols approved by the Ethic Committee of the of the Chengdu Sport University.

Experimental equipment. The German EKF Biosen C-Line blood lactate analyzer was used in the study used to collect fingertip blood samples for analysis. Time was precisely measured using a SEIKO S141 stopwatch (Japan). Heart rate was monitored using the Polar OH1 heart rate monitor (Polar, Finland). Oxygen consumption (VO_2) was measured using the Oxytone Alpha device (JAEGER, Germany). During the test, a spirometer measured VO_2 every five seconds. The criteria for evaluating maximal VO_2 were as follows: 1) the participant's heart rate reached 180 beats per minute; 2) the respiratory exchange ratio (RER) was greater than 1:3), a stable peak in VO_2 was observed during exercise; 4) the participant was unable to continue exercising at a higher intensity despite maximal effort.

Preliminary testing. Before the main experiment, participants completed a maximal oxygen consumption (VO_{2max}) test. Participants selected a date for the resting gas metabolism analysis, based on their availability; resting oxygen consumption was measured at 08:00. Participants were instructed not to eat for at least 2 hours before the VO_{2max} test, which was conducted on a treadmill using an incremental load protocol (Tab. 1). Training intensities of 90% VO_{2max} was calculated based on the VO_{2max} test results and resting oxygen consumption data. All participants familiarized themselves with the ANT task prior to the main experiment to avoid any potential learning effects.

Table 1. Distribution of load levels for the VO_{2max} Test

Steps	1	2	3	4	5	6	7	8	9
Time, min.	3	3	3	3	3	3	3	3	3
Speed, km/h	8	9	10	11	12	12	12	12	12
Slop, %	0	0	0	0	0	1	2	3	4

HIIE Training Protocol. The key factors of High-Intensity Interval Exercise (HIIE) are exercise intensity, duration, interval intensity, and rest period [16, 17]. Research by Seiler has shown that during a 1-minute HIIE session, peak oxygen consumption (VO_{2max}) reaches 82% ± 5%, while a 2-minute HIIE session can reach 92% ± 4% VO_{2max}. Furthermore, the VO_{2max} does not continue to increase with prolonged exercise duration. For example, a 4-minute session peaks at 93% ± 5%, and a 6-minute session peaks at 92% ± 3%. Based on previous research findings and preliminary pilot testing, this study determined that the optimal exercise/rest ratio for HIIE is 3 minutes of exercise to 2 minutes of rest. Based on the responses observed in the pre-test, the rest intensity was set at 25% of VO_{2max}. High Intensity Interval Exercise (HIIE) training Protocol for the experimental group (Tab. 2).

Table 2. High-Intensity Interval Exercise (HIIE) Training Protocol for the Experimental Group (N=22)

Group	Exercise intensity	Interval intensity	Exercise protocol
HIIE Group	90% VO_{2max}	25% of VO_{2max}	3 minutes of exercise, 2 minutes of rest, 5 minutes per set, 6 sets in total, 30 minutes

Attentional Networks Test (ANT). The Attentional Networks Test was presented using E-Prime 2.0 software (Psychological Software Tools, Pittsburgh, PA, USA) to display the stimuli on a 19-inch computer screen (screen resolution 1024x768 pixels, refresh rate 85 Hz). The standard procedures for ANT were followed (https://www.sacklerinstitute.org/cornell/assays_and_tools/ant/jin.fan/).

The attention network test contained three experimental blocks with 96 trials each, and each trial comprised five events: (a) first, a '+' gaze point was presented in the centre of the screen for 400-1600 ms; (b) a cue '*' signal was presented for 100ms; (c) a gaze point was presented at the centre of the screen for 400 ms; (d) afterwards, the target stimulus requiring a response was presented, and the target stimulus showing for no more than 1,700 ms disappeared immediately once the subject pressed a key. However, the target gaze point continued to show in a variable time. The duration of the target gaze point after the response was 3,500 ms minus the duration of the first gaze plus the response time. (e) The next trial was then started, and the total duration of each trial procedure was 4,000 ms.

All conditions in the experiment were equilibrated within the subject. During the experiment, the subjects were asked to look at the centre of the screen and respond as quickly and accurately as possible. A total of 24 practice trials complete feedback were conducted prior to the formal testing. The ANT formal testing protocol consisted of 96 trials. Each of the four cue conditions was performed with two target locations plus two flanker conditions plus two central letters with three repetitions (Fig. 1).

The symbol '*' indicated the cue, and the symbol '+' represented the fixation in the centre of the screen.

The attentional network test can effectively distinguish network functions from alerting, orienting, and executive control, and use the difference between reaction times in different cue conditions to represent different attentional network functions. Alerting efficiency = $RT_{no\ cue}$-$RT_{double\ cue}$; Orienting efficiency = $RT_{center\ cue}$-$RT_{spatial\ cue}$; Executive Control efficiency = $RT_{incongruent}$-$RT_{congruent}$. A higher score in alertness and orientation effects indicates greater effectiveness of the alertness and orientation networks, while a lower score in executive control effects indicates greater effectiveness of the executive control network.

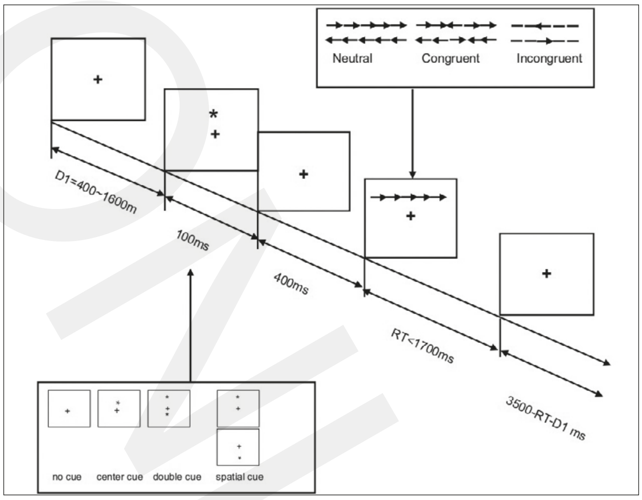

Figure 1. Schematic overview of the Attention Network Test (ANT) adopted in this study

Exercise protocol. The experiment was conducted over two non-consecutive days, with an interval of more than 72 hours between the two sessions.

On the first day, upon arrival at the laboratory, participants rested for five minutes before completing baseline measurements, including height, weight, and body composition. After recording baseline data (Pre), participants completed the Attentional Networks Test (ANT). Following the ANT, participants performed a multi-stage incremental load test on a treadmill. They were instructed to refrain from eating within two hours prior to the test.

On the second day, the experimental group was required to undergo a 30-minute high-intensity interval exercise (HIIE) session, following the established intensity from the preliminary test. Participants were instructed to reach the target heart rate within five minutes of starting the exercise, and if their heart rate was outside the target range, they were prompted to adjust their speed. The exercise experiment took place between 09:00 – 18:00 in the Exercise and Physiology Laboratory at the host university, with a temperature of 22.14 ± 1.8 °C. The control group participants were asked to watch a 30-minute documentary. To avoid influencing participants' emotional states, the documentary 'The Palace Museum 100' was selected following a pre-test. All participants in both groups were required to complete the ANT task within five minutes after either the exercise or watching the documentary.

Data analysis. Statistical analyses were conducted using IBM® SPSS® Statistics 23 software. The Shapiro-Wilk test was used to assess normality, and one-way analysis of variance (ANOVA) was employed to compare baseline data. For the remaining data, a 2 (Group: Experimental vs Control) × 2 (Time: Pre-test vs. Post-test) × 3 (three ANT attention networks: Alert vs. Orient vs Executive) repeated measures ANOVA was performed to investigate the effects of high-intensity interval exercise on the attentional network functions of athletes in different groups. Group was treated as a between-subjects factor, while Time and ANT attention networks were treated as within-subjects factors. Tukey's post *hoc test* was applied

Table 3. Physiological outcomes before and after intervention for both groups of subjects

Category	HIIE group	Control group	F	P	Category	HIIE group	Control group	F	P
Height	178.45±4.70	179.36±3.89	0.466	0.498	Systolic blood pressure at rest	115.45±7.99	118.80±6.79	1.394	0.244
Body weight	73.73±5.61	71.41±5.42	1.856	0.180	Resting diastolic blood pressure	72.23±9.01	72.20±7.51	0.028	0.869
Body fat percentage	20.64±3.44	20.14±3.51	0.217	0.644	Vo_{2max}	2890.88±299.87	2849.01±221.83	4.116	0.149
Training period	7.86±1.55	8.05±1.40	0.160	0.691	Maximum heart rate	194.10±6.45	192.85±7.09	0.092	0.763
Spirometry	3920.20±209.13	3911.65±204.90	0.471	0.497	Blood lactate at rest	1.86±0.68	1.74±0.72	0.167	0.685
Resting heart rate	63.23±4.52	61.50±4.09	0.643	0.427					

to detect significant differences between groups and times. Significance level was set at 0.05; all p-values were two-tailed.

RESULTS

Physiological data before exercise. An analysis was conducted using one-way analysis of variance (ANOVA) to compare the two groups. No significant differences were found between the control group and the experimental group in terms of height, weight, body fat percentage, years of training, vital capacity, resting heart rate, resting systolic blood pressure, resting diastolic blood pressure, maximal oxygen uptake (VO_{2max}), maximum heart rate, and resting blood lactate levels (Tab. 3).

ANT results. Repeated measures analysis of variance (ANOVA) was used in this study to evaluate the effects of high-intensity interval exercise (HIIE) on attentional network functions in youth athletes (Tab. 4).

Table 4. ANT task performance at pretest and posttest

ANT (attentional network)		df F p	η2p Effect Size
Alerting	Time	1,42 1.585 0.215	0.04 Small
	group	1,42 0.010 0.920	0.01 Small
	Time×group	1,42 0.359 0.552	0.01 Small
Orienting	Time	1,42 1.177 0.284	0.03 Small
	group	1,42 0.221 0.640	0.01 Small
	Time×group	1,42 0.219 0.642	0.01 Small
EC	Time	1,42 15.348** 0.000	0.27 Large
	group	1,42 1.974 0.167	0.05 Small
	Time×group	1,42 6.394* 0.015	0.13 Medium

* $p<.05$. ** $p<.01$.

Alert. Analysis revealed no significant main effects for time (F (1, 42) = 1.585; P = 0.215, η^2p = 0.04) or group (F (1, 42) = 0.010; P = 0.920, η^2p = 0.01), and the interaction between time and group was also not significant (F (1, 42) = 0.359; P = 0.552, η^2p = 0.01). These findings suggest that HIIE did not have a significant effect on the alertness network (Fig. 2).

Orient. Similarly, there were no significant main effects for time (F (1, 42) = 1.177; P = 0.284, η^2p = 0.03) or group (F (1, 42) = 0.221; P = 0.640, η^2p = 0.01), and the interaction between time and group was also not significant (F (1, 42) = 0.219; P = 0.642, η^2p = 0.01), indicating that HIIE had no significant effect on the orientation network (Fig. 3).

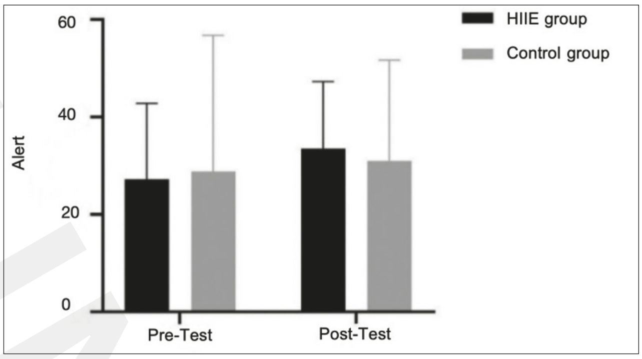

Figure 2. Alert scores before and after the intervention in both groups of subjects

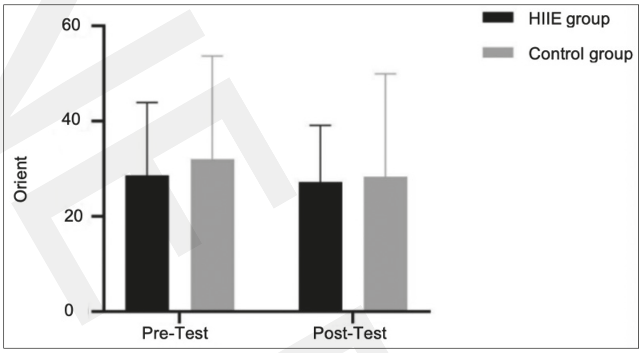

Figure 3. Orient scores before and after the intervention in both groups of subjects

Executive control. Analysis showed a significant main effect for time (F (1, 42) = 15.348; P < 0.001, η^2p = 0.27), with no significant main effect for group (F (1, 42) = 1.974; P = 0.167, η^2p = 0.05), and a significant interaction between time and group (F (1, 42) = 6.394, P = 0.015, η^2p = 0.13). Further analysis revealed no significant differences in executive control scores between the two groups before the intervention (P = 0.683), but post-intervention, the experimental group showed significantly lower scores compared to the control group (P = 0.007). Within the experimental group, there was a significant difference in executive control scores pre- and post-intervention (P < 0.001), while no significant difference was found in the control group (P = 0.332) (Fig. 4).

In conclusion, the main findings are summarized as follows: 1) after HIIE, the experimental group showed significantly lower executive control effects compared to the control group, suggesting a more significant improvement in the executive control network function in the experimental group; 2) after the intervention, the experimental group exhibited a significant improvement in executive control effects, with post-intervention scores notably lower than pre-intervention scores; 3) in the post-test of the ANT, no significant differences were found between the experimental and control groups regarding alertness and orientation functions.

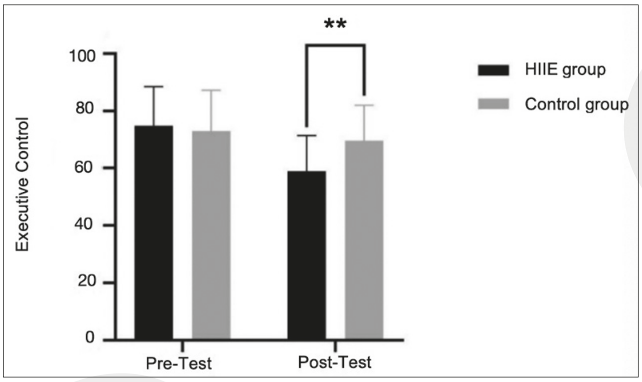

Figure 4. Executive control scores before and after the intervention in both groups of subjects.
**p <.01

DISCUSSION

The central finding of this study is that high-intensity interval exercise (HIIE) can enhance the executive control function of youth athletes. Executive control is the ability to self-regulate and resolve conflicts, and is closely related to athletes' decision-making abilities and reaction time sensitivity. The study found that after HIIE, the experimental group of youth athletes showed significant improvements in executive control. This is consistent with findings from previous literature, where numerous studies have demonstrated that acute HIIE has a positive impact on executive (cognitive) function. Kao et al. [9] found that compared to the control group, adults demonstrated faster overall reaction times and higher accuracy on the Flanker task after nine minutes of HIIE. In Zhu's study, HIIE was found to be more effective than moderate-to-intense continuous exercise in enhancing individual executive functions [18]. Similarly, research by Wang et al. showed that HIIE intervention significantly improved executive function, even in the cognitively highest-performing young individuals. Notably, Tsukamoto found that HIIE had a more pronounced impact on the brain regions related to executive function [19].

The improvement in executive control is likely due to exercise-induced activation of the dorsolateral prefrontal cortex (DLPFC), which plays a key role in cognitive flexibility and inhibition. Acute HIIE is known to elevate catecholamine levels, particularly dopamine and norepinephrine, which are essential for executive function improvement [20]. Additionally, the increase in catecholamines (such as norepinephrine and dopamine) induced by exercise may play a crucial role in enhancing executive function [21].

However, the results of this study also diverge from findings in some other research. For instance, Wang et al. indicated that high-intensity interval exercise could temporarily decrease executive function [22]. Other studies have found that when cognitive performance tests are conducted immediately after exercise, lower-intensity exercise might be more beneficial for cognitive ability than high-intensity exercise [6]. Furthermore, some studies have suggested that HIIE does not effectively improve executive function and may even have a detrimental effect. For example, Anders et al. found that after high-intensity interval exercise, participants' accuracy and reaction times on mathematical processing tasks significantly decreased. These discrepancies may arise from differences in experimental design, such as variations in exercise protocols (e.g., different acute exercise modes or intensities), the timing of post-exercise testing, accuracy in controlling exercise intensity, measurement methods, and factors such as participants' age and health status, which may contribute to these inconsistent findings. For example, the current study tested the acute effects of HIIE on youth athletes' attention network function, while some studies may have focused on more long-term effects. Additionally, youth athletes may exhibit more favourable responses to high-intensity exercise due to their stronger physical adaptability and cardiovascular fitness.

The current study also found that high-intensity interval exercise (HIIE) did not significantly affect the alerting and orienting functions of youth athletes. This result suggests that these functions may be less sensitive to acute high-intensity interval exercise, or that HIIE has a more limited impact on these sub-networks. This finding aligns with previous research, such as Chang et al.'s investigation of the effects of acute moderate-intensity aerobic cycling on the behavioural efficiency of the three attention networks. Their study found no effect on the alerting network after exercise but observed improvements in performance on the executive control network [23]. The stability of the alerting function may be related to its dependence on lower-level neural mechanisms, such as the brainstem reticular activation system, whose activity is less susceptible to significant changes from short-term exercise interventions [24]. Similarly, the orienting function, which involves the allocation and adjustment of visuo-spatial attention, primarily relies on specific brain areas, such as the superior parietal lobule and the superior frontal gyrus. The activity of these regions tends to be adjusted over a longer period, rather than being significantly altered by a single, short-term intervention.[31] Therefore, the impact of HIIE on orienting function may require a longer duration or different forms of exercise stimuli to produce significant changes. This difference may be attributed to the varying sensitivities of the neural mechanisms underlying different attention sub-networks to exercise-induced changes [23].

Thus, the results of this study further demonstrate that high-intensity interval exercise (HIIE) can significantly improve the executive control abilities of youth athletes. Executive function is a high-level cognitive skill that includes inhibitory control, working memory, and cognitive flexibility, which play a critical role throughout the lifespan. For youth athletes, enhancing executive control may improve their ability to handle complex situations and make quick decisions during competition, potentially providing a competitive advantage. Athletes should actively engage in and fully utilize the cognitive benefits of HIIE during their training. By enhancing executive control through HIIE, athletes can better cope with pressure and distractions during competitions, reducing the likelihood of attention lapses or decision-making errors caused by psychological stress.

For coaches, HIIE can be integrated into training programmes as a crucial component that combines both cognitive and physical development. By incorporating cognitive tasks, such as reaction time training or decision-making simulations into training, coaches can enhance athletes' attention allocation and response capabilities under high-pressure situations. The study's findings suggest that HIIE has an acute effect on attention network functions, particularly on the short-term improvement of executive control. Coaches may take advantage of the 'cognitive-sensitive window' post-exercise to arrange tactical analysis, technical learning, or complex decision-making training to maximize training outcomes.

Although the study results indicate that HIIE may not significantly improve alerting and orienting functions, these findings still have practical implications and research insights. For example, when designing training programmes, coaches should combine other types of interventions, such as long-term aerobic exercise, low-intensity training, and cognitive task training, to optimize these attentional functions. Future sports intervention research could design more precise training strategies targeting different sub-functions of the attention network. For instance, orienting training combined with goal-oriented stimuli or alerting training with fast-response tasks could explore the interactive effects of different exercise modes on attention networks, thereby comprehensively enhancing athletes' cognitive abilities and athletic performance [25].

Additionally, this study provides new evidence regarding the influence of exercise intensity, post-exercise cognitive testing time, and the use of the ANT as a research tool. The design of ANT allows researchers to comprehensively assess the three sub-functions of the attention network, offering more detailed information compared to traditional attention tests.

Limitations and future research. The study is limited by its focus on a specific athletic population and the use of behavioural measures alone. Future research should employ neuroimaging techniques (e.g., fMRI, EEG) to verify underlying neural changes and consider long-term HIIE interventions to assess sustained cognitive benefits.

Firstly, the sample characteristics present a limitation as the study only included youth athletes aged 12–18, with a primary focus on ball sport athletes. Although this population was highly relevant to the research objectives, the findings may not be generalized to athletes from other sports, individuals of different age groups, or those with different fitness levels. Additionally, while basic physiological variables (such as age, years of training, BMI, etc.) were controlled during recruitment, potential individual differences (e.g., genetic factors, psychological state) were not fully considered. Future research should take these individual difference factors into account and expand the sample size to explore variations in results across different sports, genders, age groups, and non-athlete populations.

Secondly, the experimental design also had certain limitations. The study employed an acute exercise intervention design, focusing primarily on the immediate effects of short-term exercise, without exploring the long-term effects of high-intensity interval exercise (HIIE). Additionally, differences in exercise protocols – particularly in terms of intensity and/or modality, along with the specific timing of tests – may have contributed to inconsistent findings [19]. Therefore, future research should adopt a longitudinal design to examine the sustained effects of long-term HIIE interventions on attention network function. It would be valuable to explore the cumulative effects and underlying mechanisms of varying intervention frequencies, durations, and exercise modes on attention function. Future studies should also consider refining the testing time points to examine the dynamic effects of exercise on attention networks at various time windows, in order to investigate the time-dependent nature of changes in attention network function, thus providing more precise timing recommendations for practical exercise interventions.

Thirdly, there are limitations in the measurement indices. Although the Attention Network Test (ANT) comprehensively evaluates alerting, orienting, and executive control functions, it does not provide insight into the underlying neural mechanisms, such as brain electrical activity or functional magnetic resonance imaging (fMRI) data. Additionally, the study did not include measures of subjective psychological experiences, such as fatigue or concentration levels, which may have potential effects on cognitive performance. Therefore, future research could incorporate neuroimaging techniques (e.g., EEG, fMRI) and biochemical markers (e.g., serum BDNF, norepinephrine levels) to further explore the neural mechanisms underlying the effects of high-intensity interval exercise (HIIE) on attention network function. Furthermore, the inclusion of subjective experience questionnaires (e.g., fatigue scales) and behavioural tasks would provide a more comprehensive assessment of the multi-dimensional effects of exercise on cognitive performance.

CONCLUSIONS

The study investigated the impact of high-intensity interval exercise (HIIE) on youth athletes' attention network functions with the use of the Attention Network Test (ANT). The results showed a considerable increase in executive control network function after HIIE, with effects being weaker for alerting and orienting networks. These findings highlight the potential value of HIIE as a specific exercise modality to enhance executive cognitive functions in adolescents. The findings have two implications: 1) inclusion of HIIE in exercise regimens may enhance cognitive performance, especially in tasks involving executive control, thus possibly improving academic and sports performance in youth athletes; 2) these findings contribute to exercise neuroscience by identifying specific cognitive processes affected by different exercise modalities.

However, some limitations must also be considered: the sample size was relatively small and included a non-diverse age and sport background in the participants, which may limit its generalizability. Larger and more diverse populations in future studies would be needed to confirm and expand results obtained.

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